CITY OF HONOLULU
REVIEW OF PLASMA ARC GASIFICATION AND VITRIFICATION TECHNOLOGY FOR WASTE DISPOSAL

FINAL REPORT

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Letter of Transmittal
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Executive Summary

This report examines the application of plasma arc gasification and vitrification technology ("Plasma Technology") for the disposal of municipal solid waste ("MSW") in four parts.

Types of Waste

First, it presents an overview of four types of waste that are currently being addressed with Plasma Technology worldwide:

- MSW includes most household trash, such as paper, plastic, metals, and organic waste. Approximately 128 million tons of MSW are generated in the United States each year. Most MSW in the U.S. is disposed in landfills or waste-to-energy ("WTE") plants. No MSW in the U.S. is disposed in a plasma facility.
- Hazardous waste includes various toxic industrial wastes. Approximately 40 million tons of hazardous waste is generated in the U.S. each year and most of it is incinerated or injected underground.
- Medical waste is a specific type of hazardous waste. Approximately 100,000 tons of medical waste is generated in the U.S. each year. It may be disposed through incineration or subjected to autoclaving, microwaves, radio waves, with the disinfected waste being landfilled.
- Incinerator ash is the residue from a WTE plant. Approximately 30 million tons of ash is generated in the U.S. each year and most of it is landfilled.

Plasma Technology

Second, the Report discusses plasma technology and the differences between Plasma Technology and state-of-the-art WTE. A plasma arc facility is a system consisting of three parts: (1) the plasma reactor, (2) environmental controls, and (3) a power generation unit (optional).

The plasma reactor is an enclosed chamber into which the waste is fed. Plasma torches provide the heat, 3000^{o}C or higher, in the chamber which converts organic material to a gas and inorganic material into a glassy slag. The plasma facility may generate electric power, using the fuel gases produced in the reactor. These fuel gases may be combusted in a waste-heat boiler, or cleaned and fed into a combustion turbine or other combustion device. However, the plasma facility must be large enough, in terms of waste throughput, to justify the cost of a power generation unit. The environmental controls on a plasma facility will be located downstream of the reactor and may include scrubbers, a carbon injection system, or a baghouse, whether or not the facility is generating electricity.

Plasma Technology is currently in the "demonstration" phase of its development. Only one small commercial plasma facility, located in Yoshii, Japan, is currently disposing of MSW (25 tpd) and has been doing so since 1999. A second facility, the EcoValley Plant in Utashinai, Japan, is in start-up mode and began receiving small amounts of MSW in December, 2002 (166 tpd). A demonstration plasma facility for the disposal of hazardous waste is located in Lorton, Virginia (10 tpd) and a medical waste disposal facility has been operating since 1998 in Honolulu (1 tpd). Several facilities in Japan are vitrifying incinerator ash.

Environmental Performance

Third, the Report examines the environmental performance of Plasma Technology and compares it to WTE. Because of the brief operating history and our inability to obtain environmental data from the Japanese operators, environmental data from an MSW-plasma facility was not available. However, environmental data from the PEPS plasma facility in Virginia which disposes of hazardous waste and medical waste was available. This information was compared with the environmental data from H-Power. The air emissions from both the PEPS plasma facility and H-Power were within their respective permit limits. In certain configurations, a plasma facility will have an advantage over a WTE plant in removing sulfur. In terms of the other regulated pollutants, including dioxins and furans, a plasma facility and a WTE plant will both meet current permit limits. The higher temperature in a plasma facility vitrifies the slag, allowing for the potential beneficial use of this material and making it less likely to leach than the ash from a WTE plant. However, the data shows that the results from the EPA's TCLP tests for both types of facilities are within the regulatory limits.

Financing Issues

Fourth, the Report discusses some of the key challenges related to the financing of an MSW-plasma facility. One of the obvious challenges is the lack of operating history for MSW-plasma facilities. The newness of this application of Plasma Technology – only one small-scale facility operating for about two years – will make investors cautious. Furthermore, the scale of the one operating facility – 24 tons per day – is well below the throughput necessary to solve Honolulu's long-term MSW disposal needs.

The developer of an MSW-plasma facility will face two kinds of risks. The first risk is the construction risk which includes the cost of designing, permitting, constructing, and testing the facility. Some of the construction risk can be mitigated through performance guarantees, equipment warranties, and insurance instruments. The second risk is the waste-disposal risk. Who will pay for the disposal of MSW at alternative sites, if the facility doesn't work? And if the facility cannot be fixed, who will pay for the City's lost opportunity to establish a workable disposal facility? The allocation of these risks will be a critical factor in the financing of a MSW-plasma facility.

Determining the cost of an MSW-Plasma facility is difficult because the facility could be configured in any one of several ways, each with its own advantages, disadvantages, costs, and risks. For example, the facility could use a waste heat boiler for the fuel gases, to keep costs down, or a combustion turbine to generate more net power. The additional net power might be economically advantageous, depending on the efficiency of the unit and the price received for electricity.

If the City wishes to obtain more concrete cost information and pursue the development of an MSW-plasma-arc facility, the next step would be to determine the City's MSW disposal needs, decide how much risk the City wishes to bear, and issue a Request for Proposals. This Report includes a section of specific questions and answers in Section 5.

Section 1
Waste and Waste Disposal

Understanding the use of plasma arc gasification and vitrification technology for waste disposal first requires some understanding of the types of waste that require disposal and the methods typically used to dispose of the waste. 'Waste' is a very general term that can be sub-divided in many different ways. For the purposes of this report, we will focus on the four types of waste that are currently being disposed in one or more plasma arc facilities worldwide. The four types of waste are:

1. Municipal Solid Waste ("MSW"),
2. Hazardous Waste,
3. Medical Waste, and
4. Incinerator Ash.

These wastes differ from each other and disposing of each presents a somewhat different set of problems.

1.1. Municipal Solid Waste ("MSW")

MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, appliances, and batteries. Taken as a whole, MSW is highly variable. That is, MSW includes many different types of materials – paper, metal, plastic, vegetable matter, glass, and animal wastes. Heterogeneity is a key characteristic of MSW.

In the "Characterization of Municipal Solid Waste for 2000" the United States Environmental Protection Agency ("USEPA") estimates that approximately 128,000,000 tons of MSW were disposed in the United States in 1999, or about 889 lbs. per person per year. According to the USEPA, approximately 70 percent of the MSW in the United States was disposed in landfills or waste-to-energy facilities in 1999.

1.2. Hazardous Waste

Hazardous waste is a broad category of wastes that includes, but is not limited to, industrial wastes, radioactive wastes, and toxic substances. Because of the dangers of handling, transporting, and disposing of hazardous waste, their management is carefully regulated by the USEPA. Because of the danger to human health and the environment, hazardous wastes must be destroyed or rendered harmless. Although hazardous wastes include a wide variety of materials, the facilities that transport, store, and dispose of these wastes typically manage a relatively narrow range of materials, such as hazardous chemical wastes or medical wastes (see below). Facilities are designed to handle specific types of hazardous wastes. The individual hazardous wastes are more homogeneous than MSW.

In its “1999 Biennial RCRA Hazardous Waste Report,” the USEPA estimated that approximately 40 million tons of hazardous wastes were generated in the United States, or about 278 lbs per person per year. According to the same report, Hawaii generated only 1,456 tons, approximately 2.38 lbs per person – the lowest total in the United States due in part to the small amount of heavy industry in Hawaii. According to the USEPA, approximately 81 percent of hazardous waste was disposed by land disposal or thermal treatment. The primary means of land disposal of liquid wastes is deepwell injection. Thermal treatment includes both energy recovery and incineration.

1.3. Medical Waste

Medical waste is one specific type of hazardous waste. The US EPA defines medical waste as “any solid waste generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals.” It includes, but is not limited to, body organs, tissue, blood-soaked bandages, needles used to give shots or draw blood, and discarded surgical instruments. Like other hazardous wastes, the disposal of medical wastes is carefully regulated. These wastes are also relatively homogeneous.

The USEPA estimates that approximately 100,000 tons of medical wastes were generated in 2000, or about 0.69 lbs per person per year. According to the USEPA, more than 90 percent of medical waste was disposed by incineration in 1999. Other methods of sterilization include subjecting it to high-frequency radio waves, microwaves, or steam auto-claving. For facilities that disinfect the material, the residue is typically landfilled.

1.4. Incinerator Ash

The USEPA, reports, that in 2000, the 102 waste-to-energy (“WTE”) plants in the United States disposed of approximately 35 million tons of MSW. The combustion of the MSW in these waste-to-energy WTE plants results in an ash which must then be disposed. The amount of ash produced represents approximately 25 percent of the amount of MSW disposed in the WTE plant. The ash from a WTE plant is less heterogeneous than the MSW.

Assuming that 25 percent of the 35 million tons of MSW disposed in WTE plants became ash, approximately 8.75 million tons of ash, or about 61 lbs per person per year, were generated. According to the USEPA, most ash from WTE plants is disposed in landfills. WTE plants periodically test their ash to confirm that it passes the standard USEPA TCLP test for leaching heavy metals.

Table 1 summarizes the characteristics of the four types of waste discussed above.

Table 1

Four Types of Waste

Type of Waste	Annual Generation (1)	Typical Constituents	Conventional Disposal Facilities
MSW (2)	888.89	Household trash, paper, plastic, metals, organics	Landfills, WTE plants
Hazardous (3)	277.78	Chemical waste, radio- active material, heavy metals	Incineration, deepwell injection
Medical (4)	0.69	Body parts, tissue, blood	Incineration, micro waves, auto-claving
Ash (5)	52.08	Incinerator ash	Landfilling

1. Pounds per person per year based on USEPA data
2. Municipal Solid Waste – Sources: USEPA; Characterization of Municipal Solid Waste, 2000
3. Hazardous Wastes – Source: USEPA; The National Biennial RCRA Hazardous Waste Report (1999 data)
4. Medical Waste – Source: USEPA; Medical Waste: Frequently Asked Questions
5. Incinerator Ash – Source: Integrated Waste Services Association

To understand the advantages and issues of disposing of these types of waste in a plasma arc facility, it is necessary to understand some basic principals of plasma technology.

Section 2
Plasma Technology for Waste Disposal

2.1. Plasma Technology

2.1.1. Background

Plasma as a method to generate heat is a proven, well-demonstrated commercial technology at work around the world. In the 19^{th} century, plasma technology was developed and used in Europe for the metals industry. At the beginning of the 20^{th} century, the chemical industry used plasma heaters to extract acetylene gas from natural gas. In the early 1960s, the United States National Aeronautics and Space Administration used plasma technology to simulate the high temperatures that orbiting space vehicles would encounter when reentering earth's dense atmosphere. In the 1980s, large-scale plasma heater processes were built and commissioned for a variety of industrial applications, particularly for metals and chemicals.

Although plasma technology has a long track record, its application to waste disposal is more limited. During the past twenty years, the use of plasma technology for waste disposal has undergone extensive research and small-scale development. It has been tested and evaluated on many types of wastes, including automobile shredder residue, sludges, asbestos fibers, medical waste, and MSW. This R&D effort is continuing and some small-scale commercial plasma facilities for disposing of waste have been operating for more than a decade.

2.1.2. Basics of Plasma Technology

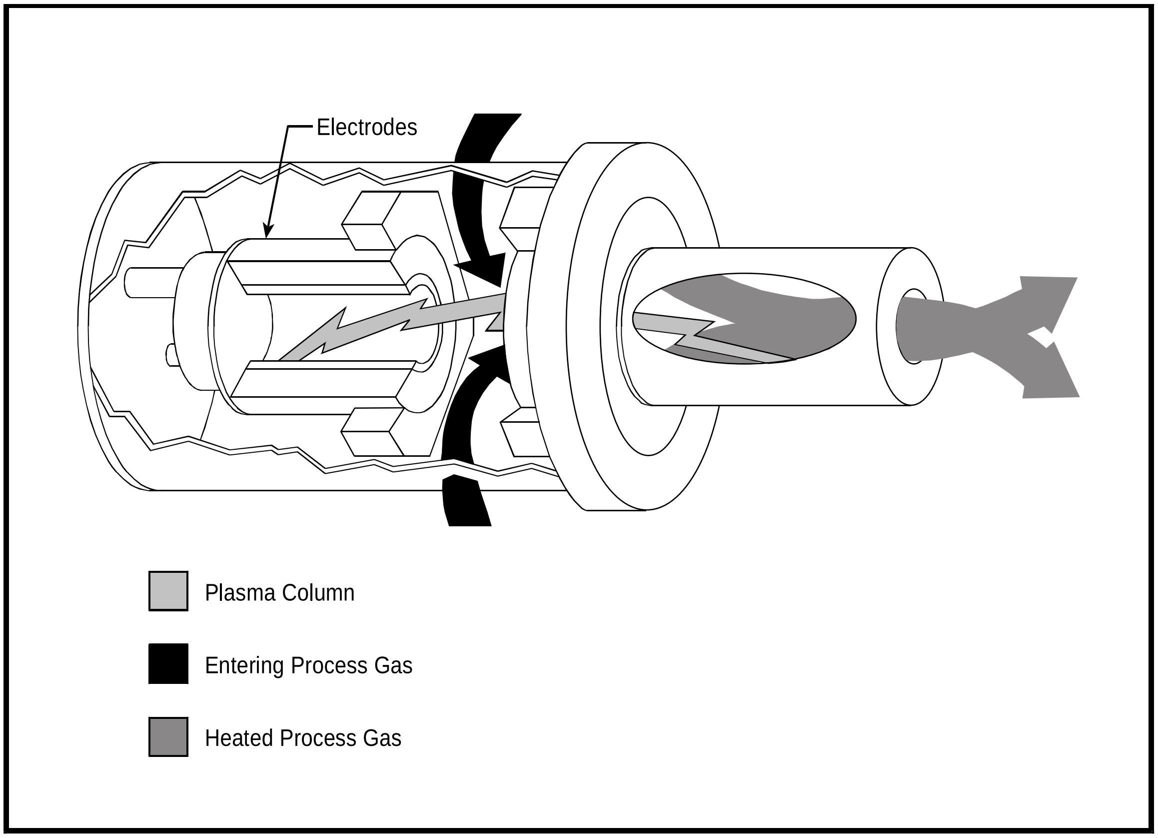
Plasma is a hot ionized gas resulting from an electrical discharge. Plasma technology uses an electrical discharge (the "arc") to heat a gas, typically oxygen or nitrogen, to very high temperatures, potentially in excess of 3000 degrees Celsius ("C"). The heated gas can then be used as a controlled heat source of a particular application. These applications can include welding, cutting, or the disposal of waste materials. In the applications of plasma arc gasification on waste materials, the amount of oxygen in a plasma reactor, as in any gasification system, is carefully controlled to eliminate combustion and promote gasification. The extreme heat generated in a plasma reactor actually pulls apart the organic molecular structure of the material to produce a simpler gaseous structure, primarily CO, H_2, and CO_2.

As applied to the disposal of waste, such as MSW, the gases heated by the plasma arc come into contact with the waste, melting or vitrifying the inorganic fraction of the waste and gasifying the organic and hydrocarbon (plastic, rubber, etc.) fraction.

2.1.3. The Plasma Reactor

The Plasma Technology resides in an enclosed reactor into which the waste is fed and processed. The gases in the reactor are heated by one or more plasma torches or electrodes. There are two types of plasma torches, the transferred torch and the non-transferred torch. The transferred torch creates an external electric arc between the tip of the torch and a metal bath or the conductive lining of the reactor wall. A variation on the transfer torch is the graphite electrode, as used in the Hawaii Medical Vitrification plant. In this case the electrical energy goes through the graphite electrode and “arcs” to the metal both similar to the arc used in an aluminum smelter. In the non-transferred torch, the arc is internal, within the torch itself and the gases are fed into the torch, heated, and escape through the tip of the torch (see Figure 1). Both types of torches have been in commercial operation for a decade.

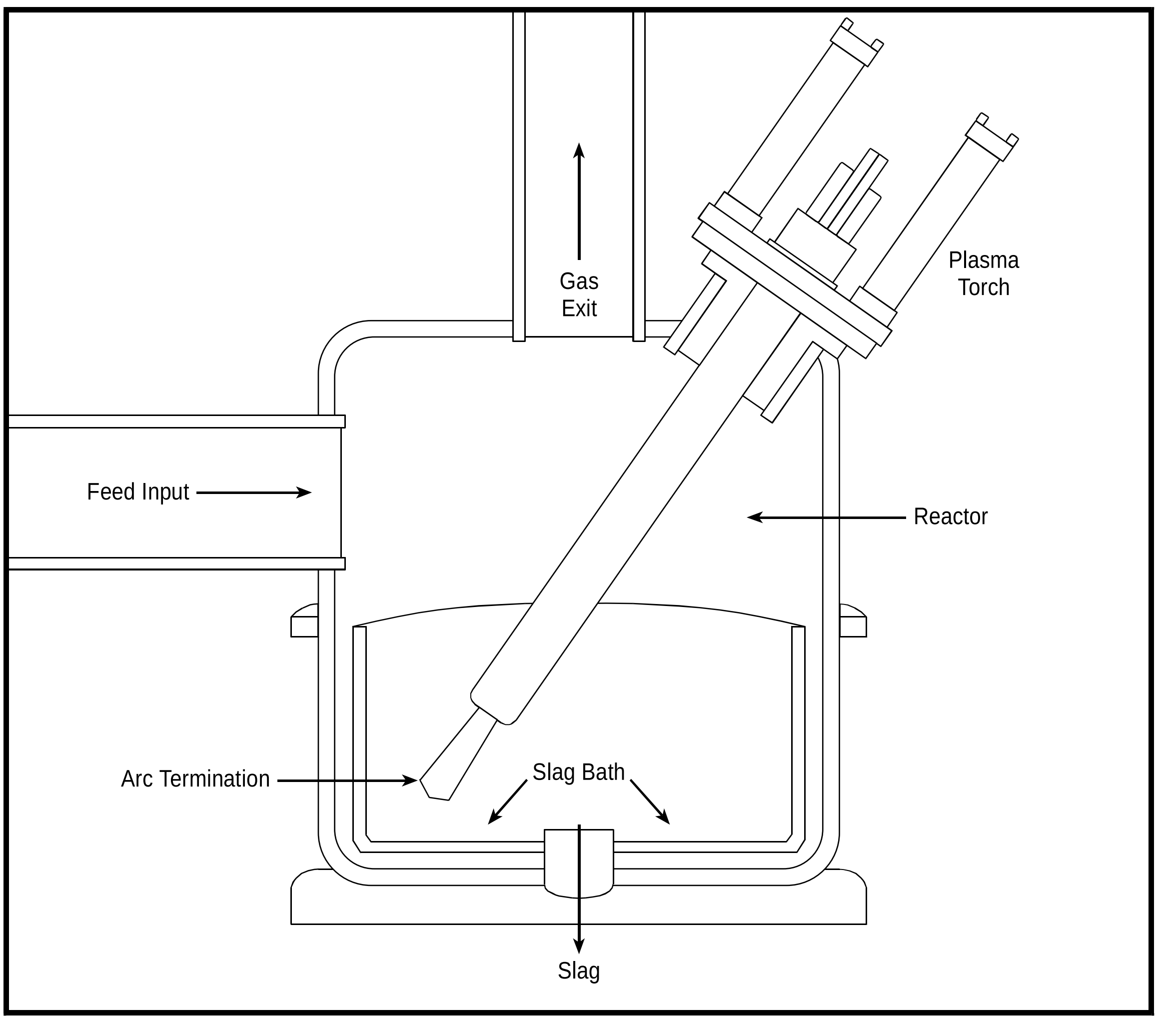
Figure 1
Westinghouse Non-Transferred Plasma Torch



There are two approaches to the current design of the plasma reactors. In the first approach, promoted by Westinghouse and Hitachi, a low pressure gas passes over a water cooled non-transferred torch, outside of the reactor. The hot gas then flows from the torch into the waste reactor to melt and gasify the MSW.

The second approach is an in-situ torch, promoted by several suppliers. Here, the plasma torch is placed inside the reactor itself (see Figure 2). This torch can either be a non-transferred torch or a transfer torch. When using a transferred torch, the electrode extends into the waste reactor and the electric arc is generated between the tip of the torch and the conducting receiver, i.e., the metal slag in the reactor bottom or a conducting wall. The low pressure gas is heated in the external arc. Alternatively, a non-transferred torch can be used in which the ionized gas is created within the torch and is projected onto the waste. In each case the electrical source for the torch is direct current.

Figure 2
In-Situ Plasma Torch Reactor



Typically, the waste enters the reactor through a point at the top or the side of the reactor and, after contact with the ionized gas, the metals and ash form a liquid pool at the bottom of the reactor. The organic portion of the waste is gasified, rises, and exits at the top of the reactor.

Proponents of the in-situ torch claim its advantages include better heat transfer to the waste and a hotter reactor temperature, resulting in more complete waste conversion. The main disadvantage is the potential corrosive effect of the waste and the gases on the torch in the reactor. Proponents of the external torch point out that this approach protects the torch from the corrosive effects of the waste and prolongs the mechanical integrity of the torches. The disadvantage of the external torch is the possibility of a somewhat lower reactor temperature resulting in less waste being converted. For a graphite electrode, the graphite is consumed over time and needs to be replaced.

Both approaches have been applied to small-scale commercial waste or medical waste processing units. The throughput of the largest external system is approximately four tons per hour and the throughput of the largest internal system is approximately 10 tons per day. Pilot units using the in-situ approach have reportedly operated at one ton per hour. The external Westinghouse/Hitachi design has been scaled up to 83 tons per day per reactor at Utashinai, Japan, currently in start-up. In addition a 14 tons-per-hour (336 tons per day) Westinghouse design is reportedly under construction in Rome, Italy.

As noted above, the Plasma Technology results in two outputs: (1) a burnable gas and (2) a glass-like slag, resulting from a process called "vitrification." The combustible gas can either be burned immediately in a close-coupled combustion chamber or cleaned of containments and used to fuel a combustion turbine power plant.

It is important to understand that certain metals, such as mercury, lead, zinc, and cadmium, may be volatilized, depending on the temperature in the reactor. That is, if the temperature is low, the metal will be melted and become part of the slag at the bottom of the reactor. If the temperature is high, the metal will be vaporized and rise with the gases out the top of the reactor. For example, lead volatilizes at 1737 degrees Celsius ("^{o}C"). Below this temperature, the lead becomes part of the slag; above this temperature, it escapes with the gases and must be captured elsewhere in the system. Mercury has a very low temperature of volatilization (about 360^{o}C) and vaporizes in almost any combustion system.

2.1.4. The Power Generation Unit

Plasma arc facilities consume power to create the plasma arc that destroys the waste. At the same time, these facilities are capable of generating power. The cost of adding power generation equipment will depend on the throughput of the facility and the type of equipment used. When the amount of power consumed by the facility is less than the amount produced by the facility, there is a net power output which can be sold and becomes a source of revenue. Currently, there are two approaches to the generation of electric power in plasma facilities.

In the first approach, the combustible gas, or synthesis gas (“syngas”), produced in the reactor is burned in a close-coupled combustion chamber and passes the hot gases through a waste heat boiler to generate steam and, subsequently, power. The resulting flue gases must be cleaned by an air pollution control (“APC”) system that is similar to the system in a state-of-the art WTE plant. The APC in this configuration is downstream of the boiler.

The second approach to generating power is to use the syngas to fuel a combustion turbine. The burning of the syngas in a combustion turbine combined cycle (“CTCC”) power plant is more efficient and will typically produce more net power than would be produced using a waste-heat boiler. However, the syngas must be cleaned before it enters the turbine. Chlorine, sulfur, mercury, and other elements that would harm the turbine must be removed from the syngas before it can enter the turbine’s combustion chamber. The system used to clear these gases would be similar to systems currently used at coal gasification plants or in the petrochemical industry, although at a much reduced scale. Typical coal gasification systems consume 2000 tons per day of coal and produce 250 MW of power. The CTCC is typically more difficult to operate than a boiler because the turbine requires gas with a relatively consistent heating value. Using a gas with a highly variable heating value may have a detrimental effect on the operation, thereby increasing operating costs. The problem is that the heterogeneity of MSW (primarily in the moisture content) results in a highly variable gas heating value (i.e., BTU content). The addition of supplemental natural gas to the syngas can overcome this problem but it introduces additional complexities and costs to the operation of the facility.

2.1.5. Environmental Controls

In addition to the plasma reactor and the power generation unit, an MSW-plasma arc facility will require certain environmental controls to avoid polluting water, air, and/or soils.

2.1.5.1. Water

All power plants consume water for cooling and steam generation. However, this water usually does not require treatment because it is simply recycled and does not pick up pollutants from the process. Plasma reactors themselves do not use a significant amount of water with one exception. That exception is facilities that burn the syngas in a CTCC. As noted above, this gas must be cleaned prior to use and the removal of chlorine, sulfur and other problem substances result in both the condensation of the water produced in the process and the water used for scrubbing that must be treated. The specific design for treatment depends on the size of the system and the type of technology. The types of equipment would include scrubbers, filters, and sorbent systems. The circulating water in these systems needs to have the problem substances removed. The costs would depend on the size of the facility and the specific type of clean-up technology used.

2.1.5.2. Solids

As noted above, the primary solid output from plasma facilities is a glassy slag, the result of melting the inorganic fraction of the waste. Any waste disposal facility generating an ash or slag is required by the USEPA to subject it to a Toxicity Characteristic Leaching Procedure ("TCLP") test. The TCLP test is designed to measure the amount of eight elements that leach from the material being tested. As Table 8 in Section 3 indicates, TCLP tests on plasma facilities, even those processing highly hazardous materials or medical waste, show results that are well below regulatory limits. In other words, the plasma arc technology melts the inorganic material so that almost none of it can leach back into the environment.

2.1.5.3. Air

The discharging of pollutants into the air is also regulated by the USEPA, as well as state environmental agencies. Air emission regulations apply to all facilities disposing of waste, including landfills, incinerators, WTEs, and plasma facilities. The emissions of concern to the USEPA include sulfur dioxide (SO_2), hydrogen chloride (HCL), carbon monoxide (CO), nitric oxides (NO_X), particulates (PM), volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). HAPs include chlorinated hydrocarbons (dioxins.). Plasma arc facilities control different pollutants in different areas of the plant. Table 2 below shows the type of emission, the location of the control device, the type of residue, and the ultimate disposal point for the residue for both types of facility configurations.

Table 2

Plasma Arc Air Emission and Control Devices

Emission	Waste Heat Boiler Control Device (1)	Combustion Turbine Control Device (1)	Residue	Disposal of Residue
SO_2	Scrubber	Absorbent (2)	Scrubber residue	Landfill
HCL	Scrubber	Scrubber/concentrator	Scrubber/concentrator residue	Landfill
CO/VOCs	Boiler	Turbine	NA – consumed	NA
NO_X	Boiler	Turbine	NA – consumed	NA
PM	Baghouse filter	Scrubber Filter	Fly ash	Landfill
Volatile Metals	Carbon filter (1)	Scrubber Filter	Fly ash	Landfill
Dioxins/HAPs	Plasma Reactor	Plasma Reactor	NA – consumed	NA

1. With a waste-heat boiler, the scrubber will be at the back-end of the boiler. With a combustion turbine, the scrubber absorbents are upstream of the combustion turbine.
2. For the combustion turbine case, the sulfur could become a product

There are two points to note in Table 2. First, plasma arc facilities, no matter what the configuration, must include some type of air pollution control systems. The cost of these facilities depends on the type of controls being used and the size of the facility. Second, the air pollution control systems for plasma facilities generate residue which must be disposed in a landfill. For example, as noted above, certain metals may be volatilized in the plasma reactor and must be captured in carbon filters which, in turn, must be disposed. Therefore, any plasma facility will require some amount of landfill capacity although less than a WTE plant. The amount of capacity required (i.e., residue generated) is discussed in more detail Section 3 of this Report.

2.2. Applications of Plasma Technology

As noted in Section 1, plasma technology is currently being used to dispose of four types of waste: MSW, hazardous wastes, medical wastes, and incinerator ash.

2.2.1. MSW

Based on our research, there are two MSW disposal facilities using plasma arc technology currently operating in Japan. We have been unable to identify any other MSW-plasma facilities operating in the rest of the world. There is one other MSW plasma facility currently reported to be under construction in Rome, Italy. There are no operating facilities in the United States and we know of no municipalities that have issued or are in the process of issuing an RFP for an MSW plasma facility.

Yoshii Facility: This plant, commissioned in 1999 and located in Yoshii, Japan, is designed to process 24 tpd of MSW in a single train. Developed by Hitachi Metals and Westinghouse Plasma Corporation, its reactor uses external non-transfer torches and sends the syngas to a waste-heat boiler. The facility does not generate electricity. Information on the air emissions and the disposition of the slag have been requested but not yet received.

EcoValley Facility: Commissioned in late 2002 and still in start-up, this plant is located in Utashinai, Japan and has two 83 tpd trains, a total capacity of 166 tpd. Although the plant has been designed for both automobile shredder residue ("ASR") and MSW, it has been using exclusively ASR during start-up. The reactor uses four Westinghouse torches and black coke is added to the base of the reactor to maintain stable operations. This facility was developed by Hitachi Metals and Westinghouse Plasma Corporation and has the same configuration as the Yoshii plant. The slag is now being tested for suitability as a roadbed material. The Japanese government helped to fund this facility.

Rome, Italy: This facility is reportedly under construction and is anticipated to be fully commissioned sometime in 2004 and designed to have a capacity of 336 tpd. It is being developed by Enel, the major Italian utility, with assistance from the Solena Group. Plasma torches will be supplied by Westinghouse, the gas cleanup system by LGL, and a Frame 6 combustion turbine from General Electric. One of the project drivers is the electric rate of 14 cents per Kwh above prevailing rate, guaranteed by the Italian Government.

Table 3 is a summary of the three MSW plasma facilities.

Table 3

MSW Plasma Facilities

	Yoshii	Utashinai	Rome
Commissioning	1999	2002	2004 expected
Throughput (tpd)	24	166	336
Feedstock	MSW	ASR and MSW	MSW
Reactor Type	External torches (3)	External torches (3)	External torches (3)
Syngas Usage	Waste heat boiler	Waste heat boiler	Combustion turbine
Net Power Generated	None	Not available (1)	Yes, amount TBD
Air Pollution Control	Baghouse (2)	Baghouse (2)	Pre-combustion
Slag Usage	NA	Now in testing	TBD

1. The results from MSW have not yet been determined.
2. The baghouse with filters is located downstream of combustion chamber.
3. These facilities use the Westinghouse torch.

2.2.2. Other Wastes

There appear to be at least half a dozen plasma facilities disposing of other types of waste. In addition, vendors who were interviewed for this report, referred to many other facilities in the planning and conceptual design stages. Table 4 lists some of the current plasma facilities processing wastes worldwide.

Table 4

Plasma Arc Technology Waste Disposal Facilities

Feedstock	Facility Location
Electric arc furnace dust	Lundskrona, Sweden
Incinerator ash	Bordeax, France
Incinerator ash	Kinuura, Japan
Incinerator ash	Chiba City, Japan
Medical waste	Hawaii Medical Waste Vitrification
Medical waste/hazardous waste	Lorton, Virginia
Radioactive waste	Radon, Russia

2.3. Comparison of Plasma Technology and Waste-to-Energy

2.3.1. Status of Technologies

The disposal of MSW using conventional waste-to-energy technology is well established. According to the USEPA, in 2000, the 102 waste-to-energy facilities, most with multiple boilers, in the U.S. accounted for the disposal of approximately 35 million tons of MSW, approximately 14 percent of the total amount of MSW generated in the United States. The 102 facilities in the United States have an average throughput of more than 900 tons per day and have, on average, been operating for more than 10 years. The oldest WTE plant has been operating continuously since the 1970's.

By contrast, disposal of MSW using plasma technology is just beginning. There are no continuously operating MSW plasma facilities in the United States and only two operating in the rest of the world. These two facilities have an average throughput of less than 100 tons per day and the oldest facility has been operating since 1999. As noted above, there are plasma facilities disposing of other kinds of waste throughout the world.

2.3.2. Energy Recovery

Modern waste-to-energy facilities are designed, built, and operated to recover energy from the waste they process. The 102 WTE plants in the U.S. produce more than 2,800 MW of electricity. Most incinerators that are too small or too inefficient to recover energy have all but disappeared in the United States because they cannot compete economically with other forms of waste disposal.

Although any plasma facility can be designed to recovery energy, not all these facilities actually do so. The economics of power generation are site-specific. Of the two MSW plasma facilities currently operating in Japan, one recovers energy and one does not. When using ASR as a feedstock, the EcoValley facility produces approximately 7900 Kw gross and consumes 3800 Kw to operate, resulting in a net positive output of 4100 Kw. Because plasma facilities, such as the Yoshii MSW-plasma facility, are relatively small, the cost of installing and operating an energy recovery unit cannot be justified.

2.3.3. Overall Efficiencies

A typical WTE facility can be expected to produce between 400 Kwh and 600 Kwh per ton of waste processed. For example, H-Power produces 534 Kwh per ton of waste processed. MSW with a high moisture content or a high percentage of non-combustibles will reduce the efficiency of any WTE plant.

The EcoValley facility reports that it is designed to generate a gross electrical output of 7,900 Kw with a plant requirement of 3,800 Kw, resulting in a designed net output of 4,100 Kw. Auto-shredder residue was used during the first phase of start-up and small amounts of MSW have been introduced recently. However, it is too early in the start-up process to determine the actual efficiencies of the facility.

Based on the performance of other types of gasifiers as compared to their combustor counterparts (e.g., coal gasification combined cycle plants), a plasma facility with a combustion turbine might be more efficient at producing electricity than a state-of-the-art WTE plant, but there are no commercial plasma facilities with combustion turbines with which to confirm this supposition. An MSW-plasma facility with a combustion turbine is anticipated to begin operation in 2004. Table 5 summarizes the differences between H-Power and the EcoValley plasma facility.

Table 5

Comparison of H-Power and EcoValley

	H-Power	EcoValley
Location	Honolulu, HI	Utashinai, Japan
Start of Operations	1987	2002
Feedstock	MSW	MSW and ASR
Technology	WTE/RDF	Plasma Arc
Design Throughput	1800 tpd	183 tpd
Net Power (1)	534 Kwh/ton	Not available
Air Emission Control	Scrubber/ESP	Quench/Dry Injection
Slag/Ash Usage	Ash is landfilled	Now in testing

1. The baghouse with filters are located downstream of combustion chamber.

2.3.4. Revenues

There are three potential sources of revenue from either a WTE plant or an MSW-plasma facility: (1) energy sales, (2) sale of other outputs, and (3) tipping fees. Revenue from the sale of energy depends on the price for electricity and the net amount of electricity generated. Presumably the electric rate will be the same, whether the electricity is generated by a WTE plant or a plasma facility. As noted above, the amount of energy recovered by a WTE or plasma facility will depend on the technology that each plant utilizes.

The sale of other outputs, such as steel, ash or slag, will depend on the price for comparable competing materials, such as landfill cover or construction materials, and are typically in the range of $0 to $25.00 per ton. In some cases additional processes, such as screening or crushing, are required to make this material market-ready.

In an open market, without subsidies, tipping fees typically make up the largest source of revenue for a waste disposal facility. The tipping fee revenues, along with the other sources discussed above, must support operating costs, debt service, and a return on capital. The current tipping fee at H-Power is $81.27, including the 12 percent recycling surcharge and the $0.35 per ton state disposal charge.

Estimating the tipping fee for a plasma facility would require information on the operating costs, debt service, and the return on capital. At the present time, it is not possible to estimate these costs without more specific information on the nature of the facility and the structure of the financial arrangement for a plasma facility in Honolulu. The project economics are discussed in more detail in Section 4 of this Report.

The difference between WTE plants and plasma facilities in terms of environmental impacts is discussed in Section 3.

Section 3
Environmental Performance

In evaluating the performance of plasma technology for waste disposal, a critical characteristic is its impact on the environment. This impact is related to the quality of the gases (air emissions), solids (ash or slag), and liquids (water) that are emitted from the facility. All commercial waste disposal facilities must meet regulations which set limits on the amount of certain substances that can be emitted. In the United States, the U.S. EPA and the individual states set those limits. In Japan, the Ministry of International Trade and Industry (“MITI”) is the regulatory body.

The only plasma facility currently processing MSW is the Yoshii facility and we have been unable to obtain testing data from this facility. The EcoValley facility at Utashinai is in start-up and will not begin to process MSW until December of 2002. To provide information on the environmental performance plasma facilities, in the absence of data from MSW-plasma facilities, we have included data from a plasma facility processing hazardous waste and medical waste.

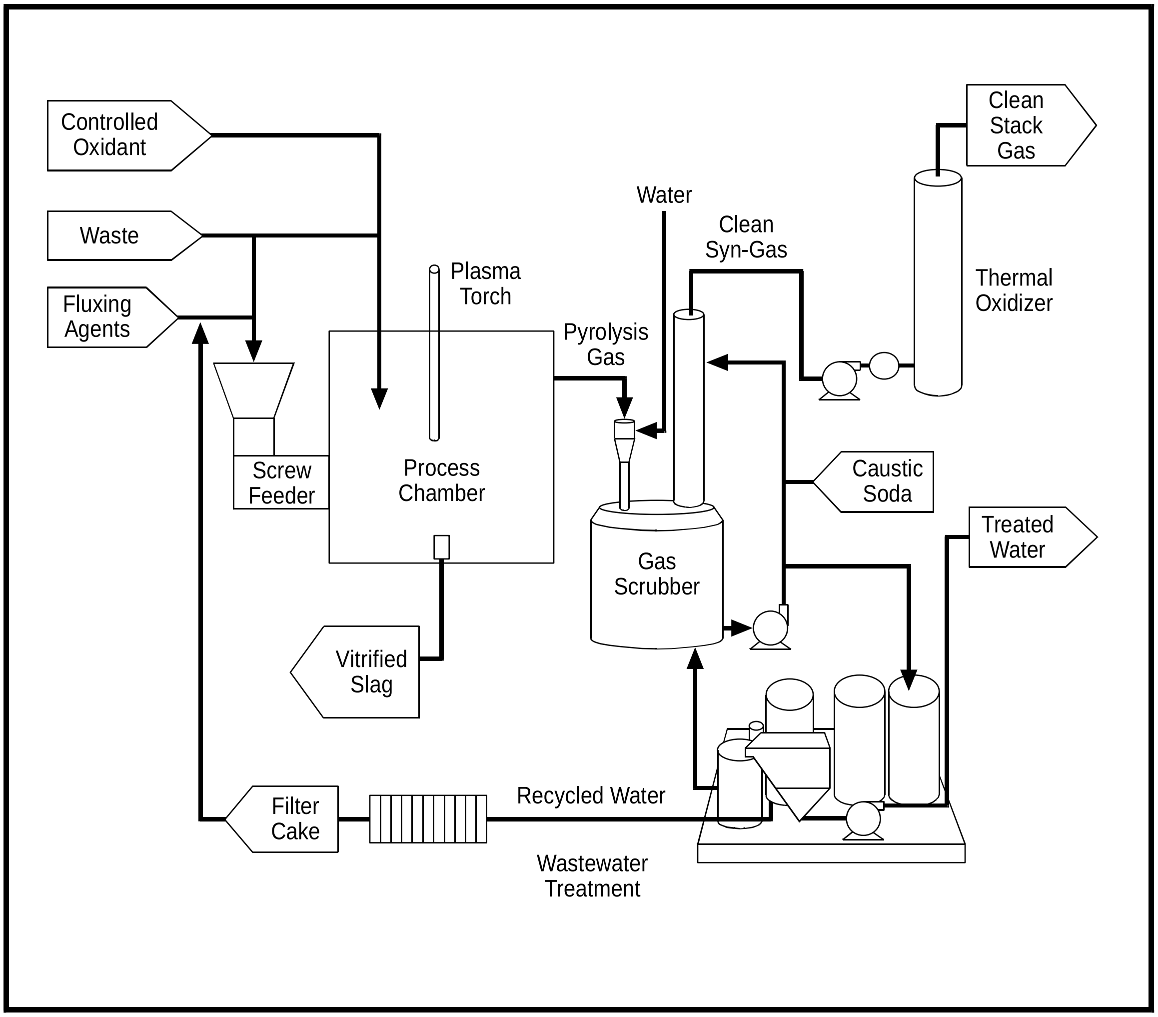
3.1. Air Emissions

To provide some information on the ability of plasma arc facilities to meet air emission permit limits, we compared the test data from the Plasma Energy Pyrolysis System (“PEPS”) Facility in Lorton, Virginia and its permit limits.

No test data was available from the Hawaii Medical Vitrification (“HMV”) facility because it has received an exemption from air testing. The exemption was granted because HMV’s current permitted throughput of one tpd is below the State of Hawaii’s testing threshold. However, the installed capacity of the HMV facility is four tpd and a new application has been submitted to increase the permitted capacity to four tpd. If the permit is approved, the HMV facility will have to begin air emissions tests.

The PEPS facility is a demonstration facility for disposal of hazardous and medical wastes in Lorton, Virginia. It has an installed capacity of 10 tdp and is powered by a 1 MW diesel generator. It has no power output because the facility’s throughput is too small and its operation is too intermittent to justify the cost of a power generation unit. The syngas produced in the reactor is combusted in a thermal oxidizer. A diagram of the PEPS facility is presented in Figure 3

Figure 3
PEPS Plasma Facility



There are two regulatory standards for air emissions that apply to the PEPS facility. The first is the Hospital/Medical/Infectious Waste Incinerator New Source Performance Standards ("HMIWI NSPS") that are issued by the USEPA. These are the minimum requirements for air emissions that a facility must meet. In addition, the Virginia Department of Environmental Quality issues an air permit with additional, stricter standards for some substances. These two requirements, as well as the actual test data from the PEPS facility are shown in Table 6.

Table 6

Air Emissions from the PEPS Medical Waste Facility

(ppm)

Substance	Pollution Control (1)	HMIWI NSPS	Permit Limit	PEPS Test Results
Particulate Matter	Wet Scrubber	34.0	32.1	17.0
Carbon Monoxide	Boiler/Turbine	0.466	0.349	0.151
Dioxin/Furan	Plasma Reactor	0.000006	No Reg.	0.00000376
Hydrogen Chloride	Scrubber	22.80	12.60	2.50
Lead	Wet Scrubber	0.0700	No Reg.	0.0277
Cadminum	Wet Scrubber	0.0400	No Reg.	0.0584
Mercury	Wet Scrubber	0.5500	No Reg.	0.4080
NO_X	Boiler/Turbine	250	No Reg.	60
SO_X	Wet Scrubber			

1. Location of the device to control that pollutant
Source: Vanguard Research, Inc

As Table 6 shows, the air emissions from the PEPS facility are below the permit limits, with the exception of cadmium. The PEPS reported that subsequent tests indicated that cadmium was within regulatory limits.

As noted in Section 1, the heating value and composition of MSW tends to be more variable than the heating value and composition of medical waste. This variability poses particular issues for an MSW facility that are typically solved through operating experience. A facility operator will learn how to optimize the facility over time, through experience.

The incineration of MSW in a waste-to-energy facility, such as H-Power, generates the same pollutants as disposal in a plasma arc facility. Table 7 shows the pollutants, location of the pollution control devices, permit limits and test results from H-Power.

Table 7

Air Emissions from H-Power Waste to Energy Facility

Substance	Pollution Control (4)	Permit Limit	H-Power Test Test Results (5)
Particulate Matter (1)	Baghouse	27	13
Carbon Monoxide (2)	Furnace	200	34.5
Dioxin/Furan (3)	Furnace	60	10
Hydrogen Chloride (2)	Dry Scrubber	29	12
Lead (1)	ESP	0.44	0.37
Cadminum (1)	ESP	0.040	0.0072
Mercury (1)	None	0.080	0.021 (6)
NO_X(2)	Boiler	250	199
SO_X(2)	Dry Scrubber	29	13

1. Emissions in units of mg/dscm@7%O_2
2. Emissions in units of ppmdv@7%O_2
3. Emissions in units of ng/dscm@7%O_2
4. Location of the device to control that pollutant
5. Average of three runs on Unit 1, Test dates June 17-20, 2002
6. Analyte was below detection limits

Source: H-Power

As Tables 6 and 7 show the air emissions from both the PEPS facility and H-Power are below their respective permit limits. It is reasonable to assume that a plasma arc facility could be constructed to dispose of MSW and operated to meet the permit limits for air emissions, since most of the pollution control equipment would be added downstream of the plasma reactor.

3.2. Solid Residue

Both WTEs and plasma facilities produce solid residue. Approximately 25 percent of the MSW throughtput in a typical WTE results in bottom and fly ash. Depending on the air pollution control system employed, approximately the same percentage of throughput would be produced, in the form of slag and other residue, from a plasma facility disposing of MSW. A WTE or plasma facility with a throughput of 200 tpd of MSW would produce approximately 50 tpd of solid residue. The environmental impact of the solid residue from these facilities would be determined in the same way. However, the slag from a plasma reactor should have some beneficial use, while currently, almost all WTE ash is landfilled.

The USEPA has established the Toxicity Characteristics Leaching Procedure ("TCLP") test for determining the amount of heavy metals that leach from incinerator ash or slag from a waste disposal facility. The TCLP test measures the presence of eight elements after acid is poured over a sample of the ash or slag. All incineration and plasma facilities in the United States must perform TCLP tests on their residue. In Japan, ash is also tested for the presence of pollutants. However, because we have not received the results of environmental testing from the Yoshii facility and no test data has been generated at the EcoValley facility, we cannot provide test results on slag from an MSW-plasma facility.

However, TCLP data is available for slag from the PEPS facility. Table 8 shows the current permit limits for the TCLP test and compares these with the test results from PEPS processing both regulated medical waste ("RMW") and a hazardous waste called agricultural blast media ("ABM"). For the purposes of comparison, recognizing that the characteristics of MSW differ from those of RMW and ABM, the results of the TCLP test results for H-Power are also presented in Table 8.

Table 8
TCLP Toxicity Limits and Test Results for Slag and Ash
(all units in ppm)

	USEPA Toxicity Limits	PEPS Facility	PEPS Facility	H-Power Plant
Feedstock		RMW	ABM	MSW
Arsenic (As)	5.0	0.200	0.200	0.025
Barium	100	NA	NA	0.66
Cadmium (Cd)	1.0	0.140	0.100	0.005
Chromium (Cr)	5.0	0.720	0.200	0.005
Lead (Pb)	5.0	0.730	0.200	0.025
Mercury (Hg)	0.2	0.020	0.020	0.00029
Selenium (Se)	1.0	0.500	0.500	0.025
Silver (Ag)	5.0	0.100	0.100	0.005

Table 8 shows that the data for slag for both RMW and ABM and the ash from H-Power are below the USEPA toxicity limits. A plasma facility may also produce residue from its scrubber, baghouse, or other pollution control equipment. This is where any metals which have been volatilized, such as mercury, lead, and cadmium, will be recovered. This non-slag residue is also subject to TCLP tests. According to the operators of the PEPS facility, the non-slag residue from the PEPS facility also passed the TCLP tests, although the test data is not available at this time. The PEPS facility is also experimenting with the recirculation of these residues through the plasma reactor to create a more closed-loop system. These experiments are still underway and the capability to fully recycle all the residue is not assured.

3.3 Water

Although some plasma systems may use water to quench and clean the gases coming from the plasma reactor, it is also possible to use a dry system. However, the choice of the combustion system (boiler or combustion turbine) will determine the extent of required water treatment. The two MSW-plasma plants now operating – EcoValley and Utashinai – do not generate wastewater. The PEPS facility has used both a dry system and a wet system that includes a wastewater treatment plant. The residue from the PEPS wastewater treatment plant is a filter cake and becomes part of the solid residue of the facility. The proposed Rome facility would need to treat some wastewater.

Section 4
Financing Issues

4.1 Facility Economics

There are two reasons why the capital and operating costs for an MSW-plasma facility are difficult to estimate. First, as discussed above, plasma arc technology is not monolithic. Existing facilities use different methods to produce plasma, to utilize the syngas they produce, and implement the necessary environmental controls. Each of the configurations for these facilities has a different cost structure. Second, there is very limited operating history for MSW–plasma arc facilities and this history is on small-scale plants.

The lack of operating history is an inherent problem with new technologies. As Table 3 shows, only two of the three MSW plasma arc facilities – the Yoshii and EcoValley plants in Japan – have been completed and one (EcoValley) is currently in start-up and has not yet begun processing MSW. Previous experience with WTEs shows that the nature of MSW, particularly its heterogeneity, presents a special set of problems that are solved only through operating experience.

There is also the matter of scale. The throughput of the existing MSW plasma facilities is well-below what the City of Honolulu will need to meet its waste disposal needs over the next 15 years, or even what it will want to provide in the short-term. The only plant now disposing of MSW, the Yoshii plant, has a throughput of only 24 tons per day. The EcoValley plant will process 166 tons per day, but it is not scheduled to begin processing MSW until December, 2002. Scaling-up a facility, regardless of the process, can present a number of technical problems that affect both capital and operating costs.

The actual capital and operating costs will ultimately depend on the way in which the plant is constructed and how the various project risks and project costs are allocated. For example, certain operating costs may be negotiated as pass-through costs, but the number and amount of these costs will not be known until bids are received and negotiations are underway.

The net operating costs will also be affected by the amount of electric power the plasma facility generates, if any, and the price it receives for this power. Electricity rates are site-specific and further complicate the determination of costs.

To begin to resolve the uncertainties surrounding the capital and operating costs, the City can issue a Request for Proposals (“RFP”), specifying the amount of waste to be delivered and the terms vendors must meet. The RFP will give the vendors a clear understanding of those risks that the City is willing to accept and those it wishes to pass on to the vendor. Responses to the RFP will provide the City with its first look at costs for a facility tailored to meet its needs.

4.2 Financing New Technologies

The financing of a new-technology project, such as a plasma-arc facility to dispose of MSW, will require both debt and equity. Typically, a project like this, in the current market environment and without a similar operating unit with several years of experience, would require a 30-40 percent or higher equity contribution or government support to secure non-recourse project debt. The equity participant(s) would accept complete risk, in return for an appropriate return on their investment.

The debt portion of the financing can be either recourse or non-recourse to the borrower. Recourse debt means that the project is backed by the developer who has sufficient resources to pay off the debt if the project fails. Non-resource debt means that the project is backed solely by the income from the project itself. A borrower with substantial resources that is willing to back the project with its own balance sheet could probably raise sufficient funds to construct a reasonably-sized plant.

More typically, Project Financing uses non-recourse debt. Since a lender of non-recourse debt will depend on the success of the project, that lender wants certain kinds of protection. For example, the engineering, procurement, and construction ("EPC") contract must be a fixed price, date certain turnkey agreement. In addition, Project Financing typically requires guarantees, warranties, and liquidated damages (at least through the successful completion of the Acceptance Tests) to be provided by the EPC contractor. These protections may be supplemented by Special Project insurance that may cover a portion of these requirements. The totality of the fixed price, the date certain, the guarantees, warranties, liquidated damages, and insurance, act to insulate the lender from technical problems with the project.

Typically, the scale-up limitations for a facility will depend on the specific applications, previous history, the level of the guarantees provided by the vendor, and other issues associated with the technology.

The difficulty with new technologies, that have not been previously financed, is that lenders typically require more stringent guarantees from the EPC Contractor. In addition, the time and effort required by the Project Developer to raise the required debt and equity can be prolonged. It is not unusual for the financing process of a new technology to take several years. Overall, using Project Financing to finance an MSW-plasma facility will depend on the terms of the EPC contract, the insurance available, and the financial strength of the owner.

4.3 Risk Allocation

Probably the most effective means of identifying the costs of MSW disposal using Plasma Arc Gasification is to issue an RFP, and one of the key issues in the RFP will be the allocation of risk. The allocation of risk between the City and any potential facility owners ("PFO") will affect the final costs to the City and may limit the ability of the PFO's to obtain financing.

The Project faces two key types of risk. The primary risk is the construction risk and is tied to the investment in the facility itself. As noted above, this type of risk can be mitigated by various guarantees, warranties, and liquidated damages from vendors. The City has made it clear that it expects the PFO to bear this type of risk.

The second risk is associated with the disposal of MSW in case the project is delayed, operates below design capacity, or doesn't work at all. To illustrate this risk for the PFO, assume that the PFO has won a 15-year contract to design and build a plant to dispose of 150 TPD of MSW for a tipping fee of $75 per ton. In the worst case scenario, the plant doesn't work, so that the PFO must repay its loan, and is responsible for disposing of 150 TPD of waste at a price that may exceed the tipping fee for the next 15 years. For the vendor of a new technology, this additional risk may limit or eliminate the interest of PFOs in responding to the RFP.

If the City accepts a portion of this "disposal" risk by paying for the cost of disposing of the non-processed MSW, the risk to the PFO for poor operations or poor project management is limited to its investment. By accepting all, or a portion of the disposal risk, the City must still address the long-term disposal of MSW. This could include the short-term landfill disposal costs and the costs of developing a new long-term alternative (e.g., the expansion of H-Power).

If the city does not accept a portion of this "disposal" risk, by charging the PFO a fee for disposal services in excess of the PFO's proposed tipping fee, the PFO's risk could increase beyond the original investment. Whether the risk is limited to a specific dollar amount or is unlimited will have a bearing on the ability of the PFO to obtain financing for the project. Although this "disposal" risk is common in the MSW facilities with which we are familiar, it is a key consideration with a new technology. In Hawaii with its limited access to alternative means of disposal, it will have a clear bearing on the PFOs' interest in the Project.

Section 5
Questions and Answers

To provide the reader with a summary of some of the key issues around plasma technology, we have included the answers to some questions that have been raised repeatedly during the preparation of this Report.

Q: Is Plasma Arc a new technology?

A: No. Plasma technology has been used for more than a century, particularly in the metals and chemical industries. Plasma arc technology for waste disposal has been used for a number of years to manage hazardous waste and vitrify ash.

Q: What is the operating history of facilities using plasma arc technology to dispose of municipal solid waste ("MSW")?

A: There are only two facilities now operating that use plasma arc technology to dispose of MSW. The facility in Yoshii, Japan, is a 10 ton per day plant that has been operating since 1999. The EcoValley facility, in Uatashinai, Japan, is a 166 ton per day plant that is in start-up. Although it is designed to dispose of MSW, it was not scheduled to begin taking MSW until December 2002. A third MSW-plasma facility is under construction in Rome, Italy, but is not scheduled to be in commercial operation until sometime in 2004.

Q: Why aren't there more plasma arc facilities disposing of solid waste?

A: Plasma facilities consume significant amounts of energy to achieve their high (3000^{o}C) reactor temperatures. This makes them costly to operate. According to proponents, plasma technology makes the most sense in places where landfill costs are very high and environmental regulations are strict, such as Japan, or where the government provides some type of financial support.

Q: Are plasma facilities more environmentally friendly than waste-to-energy plants?

A: First, it is important to remember that both WTE plants and plasma facilities, if they are properly designed, constructed and operated, can meet all current environmental regulations.

There are three important differences between a plasma facility and a WTE plant that affect environmental performance: (1) The plasma reactor operates at a higher temperature than the furnace in a WTE plant. (2) A plasma reactor operates in "reducing conditions" (i.e., with less oxygen than a WTE furnace). Plasma technology gasifies, rather than incinerates. (3) A plasma facility has <u>two</u> points at which heat is applied, the reactor and the boiler or combustion turbine where the syngas is burned. The temperature in this "secondary" chamber is <u>lower</u> than the furnace of a WTE. These three differences result in four potential differences in environmental performance between a plasma facility and a WTE plant.

- The plasma facility's higher reactor temperature vitrifies the solid residue (turns it into a glassy slag) which is less likely to leach contaminants than the ash from a WTE plant.
- The plasma facility's higher reactor temperature can more completely destroy hazardous wastes, including dioxins that may be present in MSW, than a WTE furnace.
- The reducing conditions in a plasma reactor allow the use of technologies that are more efficient at removing sulfur. A WTE furnace uses more oxygen and doesn't allow the use of these technologies.
- Because the temperature in a plasma facility's secondary chamber (boiler or turbine) is lower than a WTE furnace, less NO_X will form.

Of course these environmental advantages all come with a cost.

Q: Does a plasma facility eliminate the need for a landfill?

A: No. Even if the vitrified slag is used for construction or some other beneficial purpose, a plasma facility will produce residue from its scrubber or baghouse. The Volatile metals, such as mercury, lead, zinc, and cadmium, will vaporize in a plasma reactor, will not be melted into the slag, and have to be captured elsewhere in the system. While the amounts of residue may be relatively small, it will still be necessary to landfill some residue.

Q: Can plasma facilities produce electricity, like a waste-to-energy plant?

A: Yes. Although a plasma facility consumes a significant amount of energy in creating the plasma arc, it can produce energy if the material it is acting on has a sufficient heating value. In other words, the plasma facility can capture the BTUs in a feedstock like MSW and use it to create energy. However, because the equipment to produce the electricity is expensive, energy production doesn't make sense unless (1) the feedstock has a high heating value (lots of BTUs per pound) and the throughput is substantial. If the amount of electricity the plasma facility produces is greater than the amount of electricity it consumes, it becomes a net generator of electricity.

Q: Are plasma facilities more efficient at producing electricity than waste-to-energy plants.

A: Plasma facilities consume more energy per unit of throughput than WTEs. A plasma facility using a conventional boiler to burn the syngas will produce less net energy than a WTE plant with the same throughput. However, if a plasma facility is combined with a combustion turbine combined cycle power plant, it has the potential to generate more net power than a state-of-the art WTE plant with the same throughput.

Q: How much would an MSW-plasma arc facility cost to build?

A: We don't have enough information to answer this question. It would depend on the size of the facility, the type and configuration of the equipment, and the allocation of the project risks. The first step in finding out how much a plant would cost would be to develop and issue a Request for Proposals.

Q: How much would an MSW-plasma arc facility cost to operate?

A: Again, we don't have enough information. We would have to know the size of the plant and the type and configuration of the equipment. If the plasma facility was a net generator of electricity, we would want to know the price at which they could sell it.

Q: How does plasma arc technology differ from waste-to-energy?

A: There are at least three important differences between plasma arc technology and waste to energy. First, plasma arc is a gasification technology and waste-to-energy is a combustion technology. That is, a plasma arc facility applies heat, but restricts the amount of oxygen in the reactor to produce a burnable gas, while a WTE plant combines both heat and oxygen in its furnace to combust the MSW in one step. Second, the temperatures achieved by plasma arc (3000 ^{o}C.) are significantly higher that the temperatures in a WTE furnace (1200 ^{o}C). This higher heat results in more complete destruction of the waste and is more costly to produce. Third, higher temperature in the plasma reactor vitrifies the residue, producing a glassy slag, while the WTE produces a powdery ash.

Q: What is the role of plasma arc technology in solid waste management?

A: Plasma arc gasification technology's role in solid waste management is becoming established in the areas of hazardous waste disposal, medical waste disposal, and ash vitrification. There are facilities in Japan, Europe, and the United States currently using plasma arc technology to dispose of these three wastes. With only one 24 tpd MSW-Plasma facility in commercial operation and a second 166 tpd MSW-Plasma facility in start-up, plasma arc technology's role in the disposal of MSW, is in the nascent stage of development.